



Direct photon measurement in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with ALICE

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Abstract

The ALICE experiment has measured the direct photon spectra in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV for three different centrality selections. The measurement was performed employing a method utilizing conversion of photons into e^+e^- pairs in the detector material, and a method using the PHOS calorimeter. The two measurements were combined in order to measure direct photons over a broad transverse momentum range of $0.9 < p_T < 14$ GeV/c. A direct photon signal was observed in the thermal region $0.9 < p_T < 2.1$ GeV/c, with a significance of 2.6σ in the 20% most central collisions. The corresponding direct photon spectrum can be described by an exponential with an inverse slope parameter of $(304 \pm 11^{\text{stat}} \pm 40^{\text{syst}})$ MeV, without subtracting the hard scattering component, which is somewhat larger than the inverse slope parameter of the direct photon spectrum at RHIC energies. Within uncertainties, the data can be described by different models for photon production in heavy-ion collisions. These proceedings provide a summary of the results published in [1] and [2].

Keywords: photons, direct photons, thermal radiation, electroweak probes, QGP

1. Introduction

Direct photons are produced in all stages of ultrarelativistic heavy-ion collisions that are performed with lead nuclei at a center-of-mass energy of $\sqrt{s_{NN}} = 2.76$ TeV at the LHC. Since they do not interact strongly they leave the dense and hot nuclear medium produced in the collision unscathed. Direct photons are thus believed to provide information about all stages of the collisions [3]. At high p_T , direct photon production is dominated by hard scattering processes and can thus be used to study the validity of binary or N_{coll} scaling of high p_T particle production. At low p_T , direct photons are produced in the quark-gluon plasma and the hadron gas phase. Since these photons are from a thermal source, their spectrum follows approximately an exponential distribution and contain information about the initial temperature of the medium and its subsequent evolution. However, the direct photon spectrum at low p_T is a sum of contributions from all stages of the space-time evolution of the medium, hence the interpretation of the measured photon spectrum is not straightforward and based on assumption on the initial temperature, the expansion of the medium, and blue-shift due to radial flow [4].

An earlier direct photon measurement in heavy-ion collisions was performed by the PHENIX experiment, using internal conversion of photons [5]. The measurement confirmed the assumption of binary scal-

ing between the high p_T ($\gtrsim 5$ GeV/c) direct photon production in pp and Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV. At low transverse momenta ($1 \lesssim p_T \lesssim 4$ GeV/c), they measured an excess of photons over the expectation of N_{coll} scaled pp data that could be parameterized by an exponential function with an inverse slope parameter of $T_{eff} = 221 \pm 19^{stat} \pm 19^{syst}$ MeV. This measurement was later confirmed by a measurement using conversion in the detector material where the slope was found to be $T_{eff} = 239 \pm 25^{stat} \pm 7^{syst}$ MeV [6].

At the LHC, isolated direct photons at large transverse momentum $22 < p_T < 280$ GeV/c and $20 < p_T < 80$ GeV/c were measured by ATLAS [7] and CMS [8], respectively. These measurements confirmed the binary scaling of direct photon production at high p_T .

2. Measurement

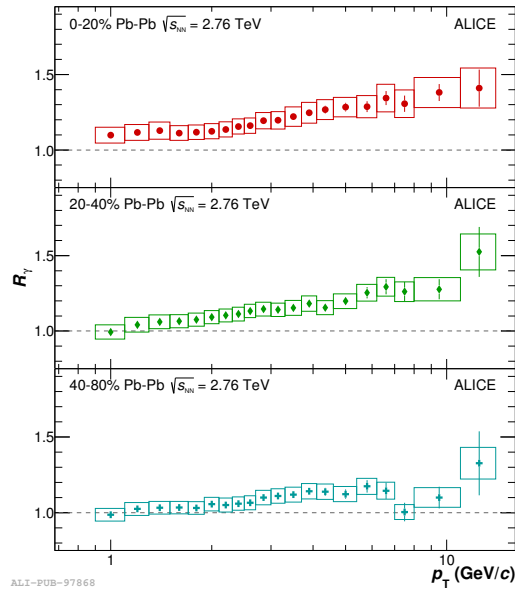


Fig. 1. Combined PCM and PHOS double ratio $R_\gamma = (\gamma_{inclusive}/\pi_{param}^0)/(\gamma_{decay}/\pi_{param}^0)$ for three different centrality selections 0-20%, 20-40%, and 40-80% [2].

ergy, size, and dispersion of calorimeter clusters, resulting in a high purity of the photon sample of 96–99%.

Both analyses use a statistical method to extract the direct photon signal from the data. First, inclusive photon ($\gamma_{inclusive}$) spectra are measured using both analysis techniques. In a next step, the decay photon (γ_{decay}) spectra are calculated, based on the measured π^0 spectrum, for each method individually. The decay photons from other mesons such as η , ω , η' are derived from the π^0 spectrum, using m_T scaling for most mesons. Only for the η meson which contributes to $\sim 10 - 12\%$ of the decay photons, a different approach was used to account for a possible flow contribution. Hence, an alternative scaling was considered, using the measured shape of the K_S^0 spectrum as a proxy for the shape of the η spectrum. For the calculation of the decay photons, an average of m_T scaling and the K_S^0 shape was used.

In order to reduce some uncertainties, the decay photon contribution was subtracted by calculating the so-called double ratio $R_\gamma = (\gamma_{inclusive}/\pi_{param}^0)/(\gamma_{decay}/\pi_{param}^0)$, and then calculating the direct photon spectrum as $\gamma_{direct} = (1 - 1/R_\gamma) \cdot \gamma_{inclusive}$. The measured π^0 spectrum was parameterized (π_{param}^0) in order to calculate the decay photon spectrum, this parameterization was also used in the double ratio.

The ALICE detector has various capabilities to measure photons and their energy. For this analysis, photons were measured in two independent analyses, using the ALICE tracking and PID capabilities by reconstructing secondary vertices of e^+e^- pairs from photons converted in the detector material, and using the ALICE Photon Spectrometer (PHOS), a highly segmented electromagnetic calorimeter. The details of the measurement have been published in [1].

The Photon Conversion Method (PCM) benefits from an excellent energy resolution at low p_T , with a π^0 peak width of $\sigma_{\pi^0} \approx 3$ MeV/c². A high purity of the photon sample of $> 90\%$ in central collisions and $> 98\%$ in peripheral collisions was obtained by using cuts on the decay topology and on electron track properties. Due to the conversion probability of $\sim 8.5\%$, the measurement is limited by statistics at high p_T , however it benefits from a large acceptance of 2π in azimuth and $|\eta| < 0.9$.

The PHOS calorimeter measures photons that leave electromagnetic showers in the detector material. It covers an azimuthal range of ~ 60 degrees and a pseudorapidity range of $|\eta| < 0.13$. Photons are measured with a high energy resolution that results in a π^0 peak width of $\sigma_{\pi^0} \approx 7$ MeV/c² at low p_T . Photons in the PHOS are selected by cuts on energy, size, and dispersion of calorimeter clusters, resulting in a high purity of the photon sample of 96–99%.

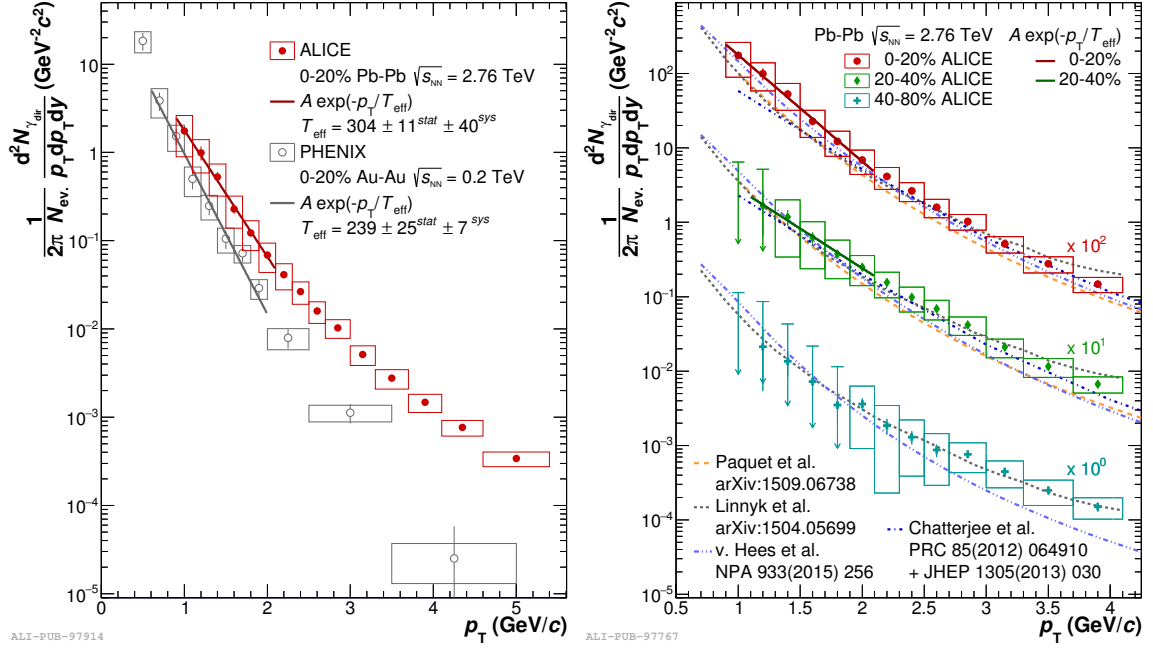


Fig. 2. Left: Direct photon spectrum for the 0-20% most central events in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV and in Au-Au collisions at $\sqrt{s_{NN}} = 0.2$ TeV [6]. An exponential fit is shown for both spectra, covering the range $0.9 < p_T < 2.1$ GeV/c and $0.6 < p_T < 2.0$ GeV/c, respectively [2]. Right: Direct photon spectra for three different centrality classes (0-20%, 20-40%, and 40-80%), compared to theoretical calculations from different models [9, 10, 11, 12]. The 0-20% centrality class was scaled by a factor of 100, the 20-40% class by a factor of 10. In addition, the 0-20% and the 20-40% centrality classes are fit with an exponential function [1].

The systematic uncertainties of the inclusive photon spectrum in the PCM analysis are dominated by the uncertainties on the material budget of the detector ($\sim 4.5\%$), and on the photon selection criteria (up to $\sim 4\%$ at low p_T). The main uncertainties of the PHOS measurement are the uncertainties on the energy scale of the detector ($\sim 9.5\%$), and on the reconstruction efficiency calculation ($\sim 3\%$ in 0-20% central collisions).

The consistency of the two analyses was checked at different levels, using pseudo experiments to calculate test statistics and subsequently a level of agreement between the analyses. The agreement was found to be 1.2 standard deviations for the inclusive photon spectra, and 0.4 standard deviations for R_γ . Hence, the results of the two analyses were combined into a single direct photon spectrum. More details on the analyses and on the comparisons can be found in [1].

3. Results

The combined double ratio R_γ is shown in Fig. 1, for three different centrality classes. A clear excess is observed at large p_T in all centrality classes. At low p_T , an excess is observed with a significance of 2.6σ in the 0-20% most central event. The significance of the excess was quantified with the same method as the consistency check between the two analyses, using $R_\gamma = 1$ as null hypothesis.

The direct photon spectrum for the 0-20% most central Pb-Pb events at $\sqrt{s_{NN}} = 2.76$ TeV is shown in the left panel of Fig. 2, together with the spectrum for the same centrality selection in Au-Au collisions at $\sqrt{s_{NN}} = 0.2$ TeV [6]. Both spectra are fit with an exponential function at low p_T in order to extract the respective slope parameters. The fit to the spectrum from [6] gives a slope parameter of $T_{eff} = 239 \pm 25^{stat} \pm 7^{syst}$ MeV, while the ALICE data were found to have a larger slope parameter of $T_{eff} = 304 \pm 11^{stat} \pm 40^{syst}$ MeV which is consistent with a larger initial temperature of the medium at the larger centre-of-mass energy.

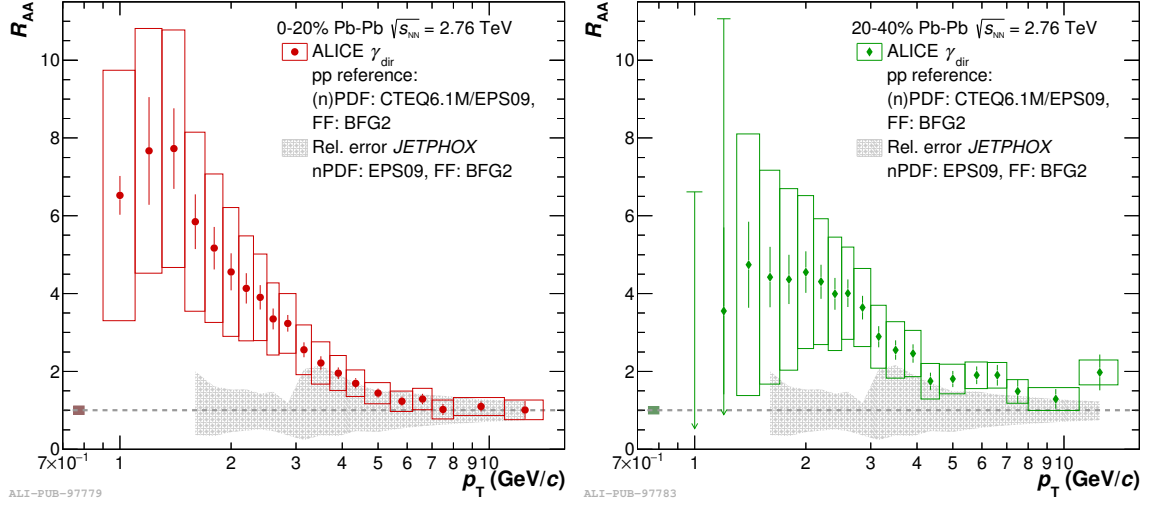


Fig. 3. Nuclear modification factor R_{AA} for the 0-20% (left) and 20-40% (right) centrality classes [2]. The pQCD calculation from [9] was used as pp reference.

Note that for the fit to the ALICE data, the pQCD contribution was not subtracted to obtain the values given here while PHENIX subtracted their measured N_{coll} scaled pp spectrum from the Au+Au data.

The direct photon spectra for all three centrality classes are shown in the right panel of Fig. 2, in comparison to various theoretical models [9, 10, 11, 12]. All models include photons from hard scattering processes calculated by pQCD. The models from [9, 10, 11] incorporate hydrodynamic calculations with different descriptions of initial conditions, different formation times τ_0 and different initial temperatures T_{init} . The model from [12] is based on a transport approach and a microscopic description of the evolution. All models agree with the data within uncertainties.

The nuclear modification factor R_{AA} can be used to quantify nuclear effects in heavy-ion collisions, it was calculated for direct photons using the pQCD calculation from [9] as pp reference. It is shown in Fig. 3 for the 0-20% and 20-40% centrality classes. R_{AA} is a different way to show the strong enhancement of the direct photon production at low p_T over the expectation from N_{coll} scaled pp collisions, as well as the validity of binary scaling at high p_T .

4. Summary

In summary, ALICE has measured the direct photon spectra and R_{AA} for different centrality selections in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, using two independent analysis methods [1]. The inverse slope parameter of an exponential function fit to the spectrum was extracted and found to be $T_{eff} = 304 \pm 11^{stat} \pm 40^{syst}$ MeV in the 0-20% centrality class. The data were compared to various models that incorporate a QGP and found to be consistent with the measurement.

References

- [1] J. Adam, others (ALICE Collaboration), Direct photon production in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV [arXiv:1509.07324](https://arxiv.org/abs/1509.07324).
- [2] J. Adam, others (ALICE Collaboration), Supplemental figures: Direct photon production in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. URL <https://cds.cern.ch/record/2102398>
- [3] S. Turbide, R. Rapp, C. Gale, Hadronic production of thermal photons, Phys. Rev. C69 (2004) 014903. [arXiv:hep-ph/0308085](https://arxiv.org/abs/hep-ph/0308085), doi:10.1103/PhysRevC.69.014903.
- [4] C. Shen, U. W. Heinz, J.-F. Paquet, C. Gale, Thermal photons as a quark-gluon plasma thermometer reexamined, Phys. Rev. C89 (4) (2014) 044910. [arXiv:1308.2440](https://arxiv.org/abs/1308.2440), doi:10.1103/PhysRevC.89.044910.

- [5] A. Adare, others (PHENIX Collaboration), Enhanced production of direct photons in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and implications for the initial temperature, Phys. Rev. Lett. 104 (2010) 132301. [arXiv:0804.4168](#), [doi:10.1103/PhysRevLett.104.132301](#).
- [6] A. Adare, others (PHENIX Collaboration), Centrality dependence of low-momentum direct-photon production in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV, Phys. Rev. C 91 (6) (2015) 064904. [arXiv:1405.3940](#), [doi:10.1103/PhysRevC.91.064904](#).
- [7] G. Aad, others (ATLAS Collaboration), Centrality, rapidity and transverse momentum dependence of isolated prompt photon production in lead-lead collisions at $\sqrt{s_{NN}} = 2.76$ TeV measured with the ATLAS detector [arXiv:1506.08552](#).
- [8] S. Chatrchyan, others (CMS Collaboration), Measurement of isolated photon production in pp and PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Lett. B 710 (2012) 256–277. [arXiv:1201.3093](#), [doi:10.1016/j.physletb.2012.02.077](#).
- [9] J.-F. Paquet, C. Shen, G. S. Denicol, M. Luzum, B. Schenke, S. Jeon, C. Gale, The production of photons in relativistic heavy-ion collisions [arXiv:1509.06738](#).
- [10] H. van Hees, M. He, R. Rapp, Pseudo-Critical Enhancement of Thermal Photons in Relativistic Heavy-Ion Collisions, Nucl. Phys. A 933 (2015) 256–271. [arXiv:1404.2846](#), [doi:10.1016/j.nuclphysa.2014.09.009](#).
- [11] R. Chatterjee, H. Holopainen, T. Renk, K. J. Eskola, Collision centrality and τ_0 dependence of the emission of thermal photons from fluctuating initial state in ideal hydrodynamic calculation, Phys. Rev. C 85 (2012) 064910. [arXiv:1204.2249](#), [doi:10.1103/PhysRevC.85.064910](#).
- [12] O. Linnyk, V. Konchakovski, T. Steinert, W. Cassing, E. L. Bratkovskaya, Hadronic and partonic sources of direct photons in relativistic heavy-ion collisions [arXiv:1504.05699](#).